BoronPlus®/PhosPlus®

Product Bulletin 517

Planar Diffusion Sources

(Formerly PB 417 or PB 617)

Troubleshooting

Introduction

Periodically a diffusion engineer will experience certain difficulties while using the BoronPlus® or PhosPlus® sources in his/her diffusion system. If this occurs, it has been our experience that slight modifications of the current processing parameters and procedures will usually bring the process back within specifications. With this in mind, the following table was compiled. It lists some of the problems that are often experienced by the diffusion engineer, it outlines the common causes of these problems, and it contains a number of suggestions that often solve the problems.

Please keep in mind that the information contained in this bulletin is very general and should only be used as a guide to troubleshooting a system. If any problem continues to persist, the process engineer is encouraged to contact us for additional assistance.

Source Problems

Problem	Probable Cause	Suggested Solution	Comments
Warpage	* Excessive temp. for source type	* Use correct source	* Brochure
	* Excessive temp. gradients across sources	* Decrease push/pull temps. and rates * Decrease ramp rate * Cool in elephant * Periodically rotate quartz boats	* PB510 * PB510
	* Sources fusing to boat	* (See "Sticking") * Periodically rotate sources within slots	* PB515
	* Tight slots	* (See "Sticking")	* PB515
	* No silicon between sources	* Always have silicon between sources during use	* PB511
Sticking: (Look for tiny pieces of boat on source or pieces of source on boat)	* Excessive temp. for source type	* Use correct source	* Brochure
	* Aging sources too long at too high of a temp.	* Follow aging recommendations	* PB511
	* Incorrect boat design	* Etch or recut slots * Increase distance across side rails	* PB515
	* Excess B_2O_3 or P_2O_5 on boat and inside slots	* Clean boat in dilute HF * Periodically rotate sources within slots	
Breakage	* Excessive warpage	* Check "warpage" and "sticking" problems	
	* No silicon between sources	* Always have silicon between sources during use	* PB511
	* Thermal shock	* Decrease push/pull temps. and rates * Decrease ramp rates	* PB510
Black Spots	* Cutting fluid in surface imperfections	* Reage in 25-100% oxygen	* PB511 * PB512B or 512P

Non-Uniform Sheet Resistivity

Problem	Probable Cause	Suggested Solution	Comments
High at Gas Inlet End	* Gas flow too high	* Reduce gas flow * Use dummy sources at gas inlet end of boat	* PB513
	* Upstream source depleted	* Replace sources * Periodically reverse boat	* (1)
	* Deposition time too short	* Increase dep. time	* PB510
High at Gas Exhaust End	* Moisture/air backstreaming into tube	* Increase gas flow * Improve seal of tube	* (2)
	* Insufficient time at temp. for downstream sources	* Tilt furnace profile * Use ramping instead of direct insertion	* (3) * PB510
	* Deposition time too short	* Increase dep. time	* PB510
High at Both Ends	* Sources nearing end of lifetime	* Replace sources	* (1)
	* Deposition time too short	* Increase dep. time	* PB510
	* Quartz boats outside flat zone	* Recheck furnace profile	
Gradually Increasing on all Silicon	* Oxide growth on silicon	* Decrease oxygen in carrier gas * Check calibration of mass flow meters	* PB513 * (4)
	* Sources nearing end of lifetime	* Replace sources	* (1)
	* Deposition time too short	* Increase dep. time	* PB510
Suddenly Increasing on all Silicon	* Sources exposed to moisture	* Reage sources * Replace sources	* PB511 * (5)
	* Air leak, broken tube	* Check fittings and tube	* (2)
	* Sources exposed to acids, etc.	* Replace sources	* PB512B or 512P
Non-Uniform Run-to-run	* Improper storage	* Improve storage	* PB514
	* Moisture in tube or carrier gas	* Check fittings, check for cracked tube	* (2)
	* Deposition time too short	* Increase dep. time	* PB510
Rapidly Changing Early in Life of Sources	* Equilibrium evolution rate not established	* Increase aging time as necessary	* PB511
High on Edge of Silicon	* Gas flow too high	* Reduce flow rate	*PB513
High on One Edge of Silicon	* Partial depletion of edge of source	* Reduce flow rate * Periodically rotate sources in boat * Use oversize sources	* (6)

Silicon Problems

Problem	Probable Cause	Suggested Solution	Comments
Silicon Damage	* Excessive glass transfer	* Use correct source for deposition temp.	* Brochure * (7)
	* Residual photo-resist	* Use "RCA Clean" *immediately* after stripping resist	* (8)
	* Moisture in tube	* Avoid back-streaming * Clean boats in dil. HF * Use improved storage techniques	* PB513 * (2) * PB514
	* Moisture absorbed by deposited glass after dep.	* Keep silicon dry by cooling in elephant * *Immediately* etch off deposited glass with dilute HF * *Immediately* rinse silicon in DI water and dry	* (9) * (9)
	* Insufficient Oxygen in gas	* Use 1/4-3% when dep. temp. is above 1000°C * Use trace amounts of oxygen (ie. 1000ppm) when dep. temp. is low * Use argon gas instead of nitrogen	* PB513 * PB513 * PB513
	* Thermal gradients in silicon wafers	* Decrease push/ pull temp. and rates * Decrease ramp rates * Cool in elephant	* PB510 * PB510
	* Failure to remove boron-silicon phase (stain)	* Use LTO and etch before drive	* PB513 * Reference [4]
Field Oxide Damage After Drive	* Moisture absorbed by deposited glass after dep.	* Keep silicon dry by cooling in elephant * *Immediately* etch off deposited glass with dilute HF * *Immediately* rinse silicon in DI water and dry	* (9) * (9)
Silicon Warping	* High thermal gradients across silicon wafer	* Decrease push/ pull temps. and rates * Decrease ramp rate * Cool in elephant	* PB510 * PB510
Staining	* Excessive boron-silicon phase on silicon surface	* Increase oxygen in carrier gas * Use high temp source * Use LTO	* PB513 * Brochure * (7) * PB513
Low Minority Carrier Lifetime	* Impurities from boat, tube, sources, etc.	* Use gettering (TCA, phosphorus dep., back surface damage, etc.) * Induce minor surface damage by decreasing oxygen in carrier gas * Age sources	* PB513 * (10) * (11)
	* Process-induced defects in silicon wafers	* Slowly anneal doped silicon wafers	* (12)
Increasing Beta or Variable Beta	* Moisture absorption of PhosPlus sources	* Insert sources in diffusion tube to dry * Store in dry environment	* (13) * PB514
Rough Polysilicon Surfaces	* Overdoping Poly with phosphorus	* Decrease amount of phosphorus depositing on silicon	* PhosPlus Brochure * References [5] and [6]

Comments:

(1) The lifetime of BoronPlus and PhosPlus sources depends upon many factors such as temperature of use, care in handling, the device being manufactured, and in particular to the gradual decrease in the B_2O_3 or P_2O_5 evolution rate (PB511). Eventually, the evolution rate will become too low to effectively dope the silicon wafers. This does not occur abruptly, but it will be observed as a very gradual increase in the sheet resistivity along the edges of the test silicon wafer located at the gas inlet (source) end of the diffusion boat. When this wafer is out of the specification limit for the process, the sources should be replaced.

(2) The condition of a diffusion system can be quickly diagnosed by using a simple "air leak test". Several unpatterned test silicon wafers are etched in dilute HF, dried and immediately placed at each end of a diffusion boat without the sources being present. An additional two or three wafers should be equally spaced in the boat between the two end silicon wafers. The boat is then placed in the diffusion furnace for 16-24 hours at a temperature of about 1000°C with nitrogen (no oxygen) or argon flowing at the normal rate used during the deposition cycle. Little oxide growth on the silicon wafers (less than about 100 Å) indicates the system is okay. Significant oxide growth on all the silicon wafers (over about 200 Å) indicates an air leak such as loose fittings or a cracked tube. Significant oxide growth only at the handle end of the boat indicates backstreaming.

(3) It is not uncommon for the sheet resistivity to uniformly increase slightly from the gas inlet end of the boat to the handle end of the boat for BoronPlus solid source systems when a flat temperature profile is used. The sheet resistivity gradient becomes more obvious at high sheet resistivities (low deposition temperatures). The sheet resistivity variations can be easily corrected by adjusting the temperature profile of the furnace so that a 5-7°C temperature gradient is formed across the boat. The temperature should be uniformly increasing from the gas inlet end of the boat to the handle end of the boat.

(4) It is important that the oxygen content of the carrier gas be accurately controlled by staying within the calibrated range of the mass flow controllers. If too much oxygen is accidentally blended into the carrier gas, a thin oxide film will grow in the windows of the patterned wafer. This oxide will mask off some of the deposited B_2O_3 or P_2O_5 and will produce high sheet resistivities.

(5) The BoronPlus and PhosPlus sources should not be exposed to steam at the deposition temperature for any period of time. If a "hydrogen-injection" type of process is desired for the BoronPlus sources, the diffusion engineer should examine Product Bulletin 310. If the BoronPlus sources were accidentally exposed to steam during an LTO cycle or during the growth of a field oxide, they can sometimes be "reactivated" by diffusing additional B_2O_3 from inside the source to its surface by repeating the aging cycle (see Product Bulletin 511). However, if the exposure of the BoronPlus sources to steam was too severe, then the sources may have to be replaced with new ones. This is also true of the PhosPlus sources.

(6) The use of 1/4" oversize sources was fairly common when silicon wafers were only 2" in diameter. However, oversize sources are rarely used when the silicon wafers are more than 3" in diameter.

(7) If it is felt that too much B_2O_3 or P_2O_5 is being deposited on a silicon wafer during a deposition cycle, it is sometimes possible to use different BoronPlus or PhosPlus sources to obtain less glass. For example, both the GS-139 and GS-245 sources can be used over the 1050-1075°C temperature range (see BoronPlus Brochure). Changing from the GS-139 source to the GS-245 source when doping the silicon within this temperature range will result in essentially the same sheet resistivity, but a significant reduction in the thickness of the deposited glass will be observed.

(8) Silicon wafers should be given the "RCA Clean" [1] immediately after removal of the photoresist. If a significant time is allowed to elapse before they are cleaned, the residual photoresist will harden, and it will be difficult, if not impossible, to remove. The resist will eventually react with the silicon surface during diffusion resulting in the creation of damage sites.

(9) If the deposited boron glassy film is more than about 500 Å, its surface becomes very hygroscopic, and the silicon quickly absorbs moisture from the room air. In severe cases, the absorbed moisture can be easily detected by the development of a milky appearance. If the silicon slices are inserted back into the diffusion furnace for further processing with this absorbed moisture, boric acid crystals (HBO_2) will form. The crystals will damage the silicon and penetrate deep into the field oxide causing additional processing problems. Moisture absorption can be prevented by (a) keeping the silicon wafers dry, (b) immediately etching off the deposited glass in dilute HF, or (c) rinsing the silicon slices in DI water immediately after they are removed from the diffusion furnace. The DI water rinse apparently washes away the hygroscopic surface of the deposited glass and prevents absorption of moisture. Experience has shown that either the acid etch or the DI water rinse must be done before the milky surface forms or it will not come off. A permanent "footprint" will be left behind that will eventually damage the silicon surface or field oxide.

(10) Normally, oxygen is included in the nitrogen carrier gas to prevent silicon surface damage. However, if the oxygen level is decreased far enough, a small number of damage sites can be purposely introduced into the silicon. These sites will tend to getter unwanted impurities in the silicon wafer with a resulting increase in the minority carrier lifetime.

(11) Tests have shown that aging the GS-139 BoronPlus sources at 1075°C for about 16 hours will result in a significant increase in the minority carrier lifetime for subsequent depositions [2]. Somewhat longer aging times would be required to observe the same effect at lower use temperatures.

(12) A systematic study on silicon wafers doped with BoronPlus sources has shown that low minority carrier lifetimes may be caused by deep level defects originating from high concentrations of boron atoms at the silicon surface [3]. Slowly annealing the silicon wafers from a temperature above 700°C anneals out these defects and the minority carrier lifetime is increased.

(13) It has been reported that if the TP470 PhosPlus sources are allowed to remain out of the diffusion furnace for several hours, the next emitter diffusion will sometimes produce higher betas of the transistor. This may be caused by slight moisture absorption of the sources resulting in increased P_2O_5 evolution rate. The higher rate results in decreased base width and a higher beta of the transistor. This can be avoided by minimizing source time outside of the diffusion furnace. The sources can be restored back to their original performance by reinserting them into the diffusion furnace at the insertion temperature for about 15 min.

For more information on this Product Bulletin or on the BoronPlus and PhosPlus dopant sources, contact the Planar Dopants Team: www.techneglas.com

References:

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3. "Processed-Induced Defects in Borosilicate Glass-Diffused Silicon", O. Aina and R. Kennedy, J. Electrochem. Soc., vol. 131, no. 8, pp 1884-1887.

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5. T.A. Carbone, "Solid Source Doping of a Double Polysilicon Capacitor", Semiconductor International, Nov. (1997) p. 89-95.

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